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Proposal for a combined methodology for renewable energy planning. Application to a Spanish region

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ABSTRACT

The article here presented aims to contribute to renewable energies development at regional level, proposing a methodology for the establishment of strategies needed to reach, in the long term, an energy system more sustainable and mainly based upon autochthonous resources.

Current energy planning models are investigated, analysing its convenience to design a sustainable energy system, and a new methodology, that combines three different approaches, is proposed. Such new "hybrid" methodology resumes advantages of territorial strategic planning methods, based upon SWOT analysis, along with characteristics extracted both from Multicriteria decision analysis techniques and expert opinion "Delphi" methods.

Nowadays, decisions concerning energy system cannot be consider under one specific criterion. Different implications, energetic, environmental or socioeconomic, derived from changes on energy development make it unavoidable to use tools and techniques that could take into account such multiplicity. It has been also intended to take advantage of the know-how acquired along the territorial strategic planning process carried out in the region to analyse, from year 1997 to 2000. This approach has allowed to integrate, under a unique methodology, tools from energy planning with those one used, and successfully tested, for the elaboration of the strategic plan for Jaén Province.

The proposed methodology has been applied to Jaén Province in order to design a renewable energy plan for the region, setting strategic action lines and fixing strategic goals to be met on year 2010 by the provincial energy system. The objective regarding electricity production from renewable resources, on year 2010, is fixed above 1630 GWh, which represents a 43% of the total foreseeable electricity consumption. Overall contribution of renewable sources in provincial energy system is finally set to 28.3%, in terms of final energy.

Contents

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1. Introduction

Energy system is currently based on a large fossil fuels dependence. It is a centralised model that have allowed a strong economic development in the last century, but that is showing a number of inconveniences which are turning it more and more unsustainable. Fossil fuels depletion, environmental damage and territorial unbalance caused by centralised energy model are significant factors to change energy structure, integrating new resources and modifying the way we use them. It is necessary to make compatible socioeconomic development with a sustainable energy model, environmental respectful and that could generate local wealth. The key issue is to address current model towards a more balanced system based on the exploitation of renewable resources.

Following this philosophy, the European Commission issued on 1997 the communication called ‘‘Energy for the future: renewable sources for energy. White Paper for a community strategy and action plan’’ establishing a European target of 12% for the contribution of renewables on year 2010 [1]. Attainment of this target at European level requires strategies and commitments at national level, as they were established in the Spanish Renewable Energies promotion plan [2] in 1999, revised as the new Spanish Renewable Energies Plan in 2005 [3], and will definitely require strategies and actions at regional level.

In this way, the paper here presented aims to contribute to renewable energies development at regional level, proposing a methodology for the establishment of strategies needed to reach, in the long term, an energy system more sustainable and mainly based upon autochthonous resources.

Current energy planning models are investigated, analysing its convenience to design a sustainable energy system, and a new methodology, that combines three different approaches, is proposed. Such new ‘‘hybrid’’ methodology resumes advantages of territorial strategic planning methods, based upon SWOT analysis, along with characteristics extracted both from Multicriteria decision analysis techniques and expert opinion ‘‘Delphi’’ methods.

We must keep in mind that decisions concerning energy system cannot be consider under one specific criterion. Different implications, energetic, environmental or socioeconomic, derived from changes on energy development make it unavoidable to use tools and techniques to take into account such multiplicity. It is also intended to take advantage of the know-how acquired along the territorial strategic planning process carried out in this province from year 1997 to 2000, to integrate, under a unique methodology, tools from energy planning with those one used, and successfully tested, for the elaboration of the strategic plan for Jaén Province.

Finally, the proposed methodology is applied to Jaén Province in order to design a renewable energy plan for the region, setting strategic action lines and fixing strategic goals to be met on year 2010 by the provincial energy system. Environmental and socioeconomic impacts derived from the goals consecution are also estimated, highlighting the positive influence on environmental preservation and socioeconomic local development as crucial issues in diffusion strategies and social actors' mobilisation.

The result of the planning process has generated a series of strategies for renewable energy development in concerned region, and a set of quantified targets to be achieved. The objective regarding electricity production from renewable resources, on year 2010, is fixed above 1630 GWh, which represents a 43% of the total foreseeable electricity consumption. Overall contribution of renewable sources in provincial energy system is finally set to 28.3%, in terms of final energy. On the other hand, planned development of renewables from current situation shows an increase of 42.2%, standing out mainly development of solar energy, both thermal an photovoltaics, which are showing an increase above 2000%.

2. The need of renewable energy planning

Energy sector configures a strategic area inside territorial socioeconomic system. On one side, energy supply constitutes a basic service for citizen's daily life and, on the other hand it represents a fundamental item on progress and economic development. This is the reason why energy policies and planning process have traditionally intended to assure energy supply on optimal conditions of security, quality and price.

In the past, national energy planning aimed to determine the infrastructure investment program to be carried out in a defined time period. However, on the new legal frame, most of the energy planning is recommended, being respectful with private enterprise, and reserving as binding planning only great energy transport infrastructures.

In spite of above mentioned, inconveniences derived from current energy model imply the need to drive energy system toward more sustainable levels, establishing strategies to encourage energy diversification and solid commitment with renewable energies. In this context, planning processes became essential to fix regional targets and to foster the involvement of public and private actors in objectives attainment.

3. Different approaches to renewable energy planning at regional level

Different techniques have been traditionally used for renewable planning purposes at regional level. In this section, techniques currently used for energy planning purposes are analysed, focusing on those ones related to sustainable development processes and regional level scope. As we will highlight, multicriteria decision techniques, Delphi surveys and territorial energy planning constitutes the most referred approaches on literature.

3.1. Multicriteria decision techniques

Multicriteria decision techniques were developed profusely in the 1960s. Classic methods come from that decade, when Goal Programming and ELECTRE (elimination and choice translating reality) method were proposed. On the 1970s new methods and refinements of existing ones were developed, and finally on the 1980s support from computer sciences has allowed a fast growth in applications and results from multiple criteria decision making (MCDA) techniques [4].

In general, all multicriteria decision aid techniques are based on the identification of a number of alternatives ($A_1, A_2, \ldots, A_m$); the selection of assessment criteria ($C_1, C_2, \ldots, C_n$); and determination of results of the assessment of each alternative, A_i, for each one of the criteria. Resulting matrix, $[a_{ij}]$, common to all MCDA methods, is usually called *Decision Matrix* (Fig. 1).

MCDA techniques are being successfully used in many different planning processes. Although there are many different MCDA methods (optimisation, goal aspiration or outranking models), steps to be followed are similar in all of then: problem definition, identification of alternatives, criteria selection, decision matrix elaboration, weights assignment, prioritization and decision making.

Linkov et al. [5] presents the methodology of decision process implementation in different environmental agencies in the US and Europe. They reveal that, despite of the fact that decision process implementation is often based on physical modelling and engineering optimisation schemes, agencies are beginning to implement formal decision analytical tools, especially multi-criteria decision analysis, in environmental decision making. They also highlight the relation between MCDA general steps, as described above, and general planning processes.

Under energy scope, the need to consider environmental, technological and social factors on energy planning has encouraged the use of multicriteria decision techniques. Among different MCDA techniques, Analytical Hierarchy Process (AHP), preference ranking organization method for enrichment evaluation () and ELECTRE method have been widely used in energy planning, in accordance with data compiled by Pohekar and Ramchandran [6].

ELECTRE method is based on the outranking relations established between each pair of alternatives. Concordance matrix and discordance matrix are then elaborated to generate a selection or a ranking of the different alternatives. It has been successfully used for renewable energy planning as shown by Beccali et al. [7]. They assessed an action plan for the diffusion of renewable energy technologies at regional scale, using a multicriteria approach with twelve evaluation criteria.

ELECTRE has also been utilised, as reported by Georgopoulou et al. [8], to elaborate a new energy strategy for Crete Island. It is advocated by these authors the use of MCDA techniques to select alternatives energy policies at regional level, mainly on high renewable resources regions. MCDA tools utilisation allows, in these cases, to take into account the environmental dimension, as well as technical, economical and political criteria. However, it is also emphasized the fact that we are dealing with "decision aid" techniques far from "decision making" techniques and, in this sense, the application of one of these methods only represents one of the steps to follow.

		Criteria					
		C_1	C_2	...	C_j	...	C_n
Alternatives	A_1	a_{11}	a_{12}		a_{1j}		a_{1n}
	A_2	a_{21}	a_{22}				
	...						
	$A_{i,}$	a_{i1}			a_{ij}		a_{in}
	...						
	A_m	a_{m1}			a_{mj}		a_{mn}

Fig. 1. Decision matrix diagram in a MCDA process.

Other authors, as Nigim et al. [9], take advantage of AHP as community decision support on energy projects implementation. MCDA has been used by a workgroup in Canadian Waterloo region, to determine priorities among five different renewable energy projects by means of six criteria that assessed both impacts and project feasibility. A process based upon group participation was developed, and results were successfully compared with those generated by a linear programming tool. Nigim et al. analyse the strong dependency between decision aid methods used, and expert opinion made to assess the hierarchy elements weight. They consider that, finally, MCDA tools have to depend on intangible aspects and subjective opinions of involved people, and they propose the use of objective criteria, as net project value, to minimise this point.

On the other hand, the use of PROMETHEE methodology is also rising. Cavallaro [10] presents a multicriteria integrated system to assess sustainable energy options that has PROMETHEE technique as the basis of its development, and applies it to the Italian Messina region. It is important to highlight that, in this case, net flow (defined as difference between positive and negative flow) is used to reach a complete outranking among alternatives.

Furthermore, a combination of MCDA methods, either in parallel or sequentially applied, may also be a proper selection in energy planning. Loken [11] describes different combination uses from research literature that include AHP along with PROMETHEE; AHP along with TOPSIS (technique for order preference by similarity to ideal solutions); and AHP along with GP (goal programming). Loken also advocates the suitability of MCDA methods as planning tool in local energy system, where several energy sources and several energy carriers are involved.

3.2. Delphi techniques

Delphi techniques have also been a popular tool for preparing forecasts and planning purposes. Landeta [12] acknowledges that, since its first application up to current applications in a huge diversity of fields such as higher education, public health, information systems, production sector analysis or political options assessment, the technique has been refined and adjusted to different uses.

In recent years, it is being used as an effective method in long term planning related to sustainable development. In this sense, Shiftan et al. [13] suggest the use of two scenarios constructed by means of a Delphi expert-based survey. Other authors, as Popper and Dayal [14] propose the utilisation of Delphi, assisted by a web-based survey, combined and supported by a geographical information system (GIS) to promote sustainable development in development countries.

3.3. Territorial and rural energy planning methods

Participatory approaches for energy planning implementation are been extensively used in rural areas and development countries. Williams [15] reflected on the use of traditional strategic planning methods for designing sustainable development strategies, and advocated changing the model to "strategic architecture" instead of "strategic plan", in order to plan the things to be done today to modify the future. He also emphasized the process more than contents and actors more than the structure.

Participation is an essential item in these processes. In this sense, a rural energy development planning in India is presented

by Neudoerffer et al. [16], who verify that energy programmes launched by Indian government have got a limited success due to the lack of mechanism to assure the implication of final users, and present the main conclusion of a research project to develop planning methodologies and tools to facilitate public participation. Anderson and Doig [17] also highlight the importance of participation techniques to implement, in a successful way, energy plans and projects at rural areas.

The case of Jaén Province, which was presented by Terrados et al. [18], confirms the suitability of this kind of approaches when society implication is essential. Authors conclude that management tools used in territorial strategic planning processes, especially SWOT analysis, can be successfully used by public administrations as proper tools to search and select strategies that may help them in the redesigning of the regional energy system.

3.4. Other techniques

Apart from above mentioned techniques, optimisation methods such as EFOM (energy flow optimisation model), as described by Cormio et al. [19], have been used to support planning processes. In this case, authors executed several simulations on the Apulia region energy system, in Italy, to prove the suitability of combined cycle installations, wind energy and biomass exploitation as environmental friendly technologies to be promoted.

Other techniques, concerning energy model generators, are being currently used for the purpose of strategic energy planning and decision making. Pietrapertosa et al. [20], and Salvia et al. [21], make use of the MARKAL models generator to develop medium-term strategies and climate protection policies at Basilicata region, in Italy. They implemented a MARKAL model specific for the region in order to assess the contribution of local energy systems to the achievement of national targets.

3.5. Combined methodologies

Combination of SWOT analysis and Delphi techniques has been successfully used in planning processes related with local and regional development. Zwaenepoel [22] proposes an approach based in an initial SWOT analysis and a later use of the Logical Framework analysis that make use, as inputs, of SWOT analysis outcomes. The process includes, inside SWOT methodology, an expert survey in order to reach a consensus prior to launch the Logical Framework analysis.

We can also consider as a combined model the one presented by Benavides and Quintana [23] who applies it to Strategic Planning at Universities. In this case, a round of talks to experts is utilised as a support process in SWOT matrix elaboration.

There are other hybrid models using Delphi techniques as a support of a multicriteria decision making analysis. It can be highlighted contributions by Aragonés [24], called PRES II Multi-expert methodology, and also by Curtis [25], who proceeded with an eighty experts Delphi panel to assign weighs on 20 attributes of an ecosystem that was evaluated by means of MCDA.

4. Proposal for a new renewable energy planning methodology

On the basis of the analysis of planning techniques already made in previous section, it can be deduced that all of the three methodologies have significant advantages and useful contributions for the sketching of strategies and action lines for renewable energies development.

Therefore, we can infer that a combination of those methods, in order to take advantage of their positive characteristics, will lead us to strengthen the effectiveness of the results, complementing their main virtues.

The new approach, here proposed, combines advantages from the three techniques commonly used in regional energy planning: multicriteria decision techniques, expert opinion and SWOT analysis.

For this, the basic structure consists of seven phases:

1. Initial diagnosis of regional energy system.
2. Diagnosis configuration as SWOT matrix.
3. Initial selection of strategies through SWOT analysis.
4. Validation and assessment of strategies by means of experts opinion.
5. Ranking of alternatives applying MCDA.
6. Reference plans analysis.
7. Final strategies selection and targets establishment.

This scheme is also useful to assure the involvement of stakeholders in the planning process. Fig. 2 illustrates the whole framework and shows by means of dark lines the main path, and by means of dotted lines the expected contributions of experts and social community.

5. Methodology implementation

Following, it is described, step by step, the procedure to implement proposed methodology.

5.1. Phase 1. Initial diagnosis of regional energy system

A deep diagnosis of regional energy situation is needed as a first step. It should be important to focus on autochthonous resources potential and usual application of them.

5.2. Phase 2. Diagnosis configuration in SWOT matrix

SWOT methodology will allow us to arrange energy system diagnosis in accordance with a matrix basis (strengths, weaknesses, opportunities and threats). In order to put in objective terms the design of matrix quadrants, special definitions of matrix elements are suggested as follows:

- *Strengths*: Variables, characteristics and/or circumstances of regional energy system which contribute to its development and growth, improving its service capacity and sustainability.
- *Weaknesses*: Variables, characteristics and/or circumstances of regional energy system which limit its development by means of reducing its service capacity and sustainability.
- *Opportunities*: Variables, characteristics and/or circumstances of external environment which may impact on regional energy system future operation, making its development easier and/or improving its sustainability.
- *Threats*: Variables, characteristics and/or circumstances of external environment which may impact on regional energy system future operation, slowing its development down and/or worsening its sustainability.

5.3. Phase 3. Initial selection of strategies through SWOT analysis

SWOT analysis will also be used to generate strategies for improving current situation. In this phase, it will be useful to confront elements of internal quadrants (S/W) with elements of external quadrants (O/T). This confrontation leads to strategies definition, and will generate four kinds of strategies:

- *Survival strategy*: The one that may avoid that an energy system weakness could favour a threat.
- *Reorientation strategy*: The one that may change a weakness in order to take advantage of an opportunity.

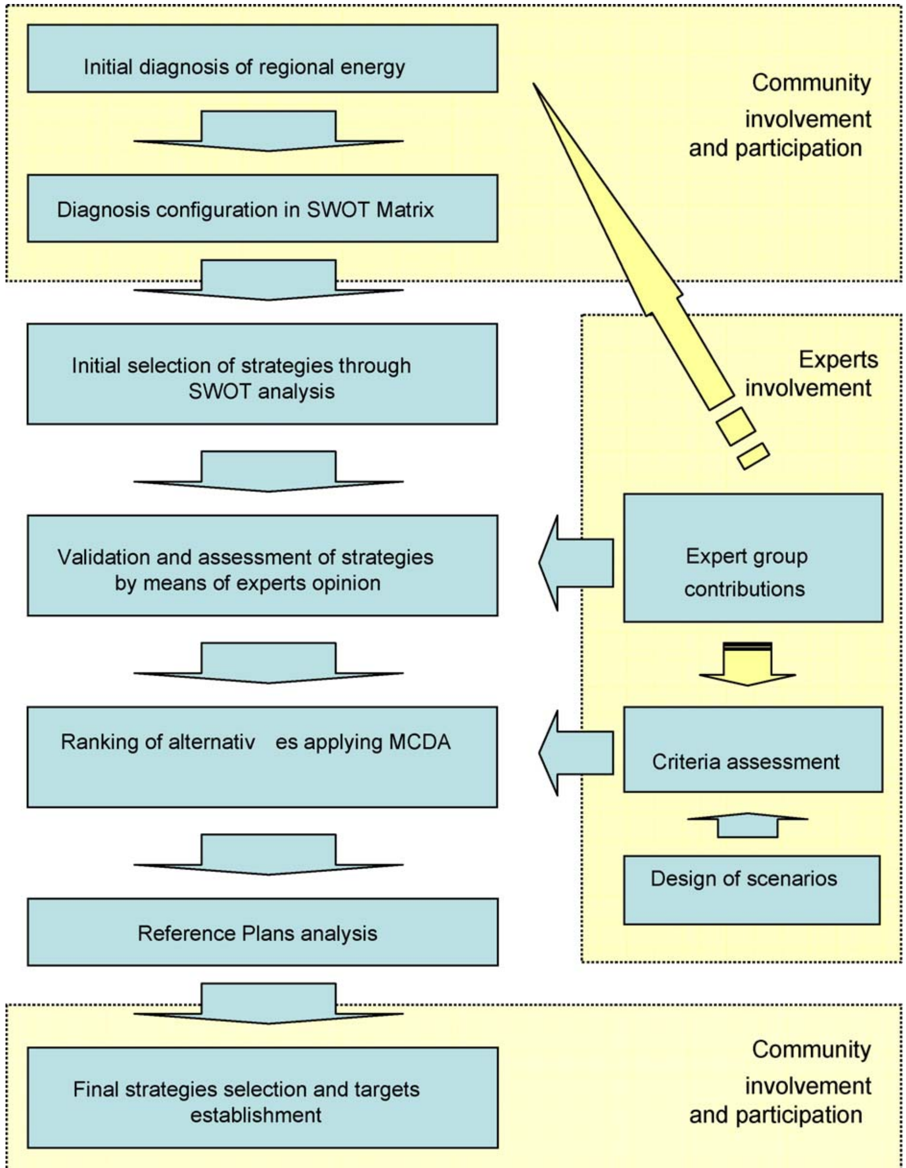

Fig. 2. Scheme of proposed RES planning process.

- *Defensive strategy*: The one that counteracts the effect of a threat by means of harnessing an energy system strength.
- *Offensive strategy*: The one that allows development of an strength to take advantage of an opportunity benefits.

5.4. Phase 4. Validation and assessment of strategies by means of experts opinion

Delphi methodology will be used to validate strategies derived from SWOT analysis and to obtain quantitative estimates upon such strategies. It is also possible to generate new strategies in this phase or to correct current ones. Initial use of SWOT technique as a tool for strategies selection will allow us to reduce the number of rounds in Delphi process, speeding up expert consensus since a more structured information is provided to them.

5.5. Phase 5. Ranking of alternatives applying MCDA

In this phase, a multicriteria analysis is conducted to establish a rank comparison among alternatives. It is proposed, as a consequence of our own experience, that the quantitative assessment derived from expert opinion will be incorporated to MCDA as an additional and specific criterion.

The use of multicriteria decision analysis combined with expert judgement provides us with a sounder result, strengthening subjective group opinion with objective data analysis. Furthermore, current software applications are allowing planners to perform simulations and sensibility analysis in a quicker and easier way. This characteristic can be useful to value the result robustness.

5.6. Phase 6. Reference plans analysis

We can have available plans, in an upper level, which may concern the region subjected to the analysis. If it is the case, these plans have to be studied and the general targets must be extrapolated to obtain low lever targets applicable to our region scope. The objectives derived from our methodology have to be consistent with those specified in the reference plan.

5.7. Phase 7. Final strategies selection and targets establishment

Finally, in the light of MCDA results and reference plans, we should choose strategies to be incorporated to the plan and we should establish quantitative targets for each one of the renewable energy sources.

6. Application of proposed methodology to Jaén Province

The methodology has been applied to Jaén Province, a southern Spanish region whose energy system is currently mainly dependant on fossil fuels. It was pursued the definition of a series of strategies for renewable energies development and the establishment of energy targets to be achieved in year 2010.

6.1. SWOT analysis

First of all, a diagnosis of the provincial energy system was accomplished. Such diagnosis was structured through a SWOT matrix where strengths, weaknesses, opportunities and threats were identified. Deployment of SWOT analysis, comparing the different sectors of the matrix, allowed us to define a set of possible strategies that were segregated on 28 defined actions (Table 1).

Table 1
List of actions to be assessed.

Electrical power generation from biomass
1. Installation of combustion cycle power stations (10–15 MW) fuelled by olive oil industry residues
2. Installation of combustion cycle pw. stations (10–15 MW) fuelled by olive pruning residues
3. Installation of gasification-based pw. stations (10–15 MW) fuelled by olive pruning residues
4. Installation of gasification-based pw. stat. (10–15 MW) fuelled by wood industry residues
5. Installation of biogas plants fuelled by olive oil industry residues (5–10 MW)
6. Installation of biogas plants fuelled by cattle wastes (5–10 MW)
7. Installation of CHP plants for the exploitation of water treatment station biogas (0.5–2 MW)
8. Installation of biogas plants fuelled by urban residues (1–5 MW)
Thermal power generation from biomass
9. Installation of biomass domestic heating systems
10. Installation of biomass heating systems at educational centres
11. Installation of biomass heating systems at industry and services
Hydroelectricity
12. Building of new hydro plants on existing and future dams (10–30 MW)
13. Building of new small hydro plants on waterfalls and watercourses (0.5–10 MW)
14. Refurbishing of old hydro plants (0.25–5 MW)
Isolated photovoltaic systems
15. Domestic isolated PV systems (2–5 kW)
16 Isolated PV systems in farming applications (2–5 kW)
Grid connected photovoltaic systems
17. Domestic grid connected PV systems (2–5 kW)
18 Grid connected PV systems at companies and public administrations (30–100 kW)
19. Large grid connected PV systems (200–1000 kW)
Solar-thermal heating systems
20. Single-family domestic solar-thermal heating systems installation
21. Communities domestic solar-thermal heating systems installation
22. Solar-thermal heating systems installation at hotels and services sector
23. Solar-thermal heating systems installation at industry
Solar-thermal electricity
24. Solar-thermal gas hybrid installations (2–20 MW)
Wind energy
25. Low-power isolated wind systems (5–250 kW)
26. Wind farms (5–30 MW)
Other actions
27. Energy crops exploitation in combustion cycles
28. Biofuel generation through energy crops

6.2. Delphi survey

Following SWOT analysis application, an expert survey, based on Delphi technique, was performed. In this case the number of experts to participate was limited by the characteristics of the matter to study. We needed to contact experts on renewable energies in general, and who should also know about provincial reality. Such limitation would meant to reject scientifics who were specialized only on a determined renewable resource and were unable to develop a forecast on the rest of sources and, on the other hand it also would meant to reject renewable energies researchers who were unaware of our regional situation.

Thirteen experts were initially selected, and nine of then finally got committed in the process. They represented the main Institutions, Organizations and Enterprises connected with provincial energy field (University, Energy Administration, Provincial Energy Agency, Electrical distribution Company, Andalusian Energy Agency, Andalusian Institute of Renewables, Andalusian Development Institute and Ecologist Associations).

The questionnaire sent in the first round considered 28 actions to be executed, and experts were required to assess, in one hand, the relevance of those actions for renewable energies development and, on the other hand, to estimate the target to be met by the action (power installed, number of installations, . . .) by year 2010. They were also required to propose additional actions.

As a result arising from the first round, all of the actions were judged very positively with ten alternatives above four points (on a 1–5 scale) and another fifteen alternatives above three points. A high degree of consensus was also achieved. Referring to the estimation of targets, discrepancy among experts was higher. In order to value the degree of consensus, it was used a *Variation Factor* (ν) as proposed by Landeta [12], who defines ν, as:

$$\nu = \frac{\sigma}{\mu}$$

where σ is the sample standard deviation and μ is the sample arithmetic mean. It could be checked that only three alternatives reached values of ν lower than 0.5.

A second round was then accomplished. Consensus among experts was increased both in valuation of alternatives and in target estimation (Table 2). Variation factor decreased, in a widely manner, and consensus suitable level was judged as appropriate.

On the other hand, new alternatives proposed in the first round were negatively appreciated. Average valuation was 1.8 with standard deviation of 2. Therefore, they were discarded and not included in the model.

6.3. Multicriteria analysis

Finally, a Multicriteria analysis was performed in order to fix priorities among alternatives. A set of 10 criteria were initially defined to be assessed in each of the alternatives. Later, an eleventh criterion was added to incorporate results from Delphy analysis into MCDA. In this way, assessment provided by experts survey was consider as an additional criterion. Therefore, up to eleven criteria were defined, grouping them in four different categories.

- *Technological criteria*
  1. Total primary energy saved.
  2. Maturity of technology.
  3. Technical know-how of local actors.
  4. Continuity and predictability of resource.

Table 2
Result of Delphi survey. First questionnaire, round two.

Action	Mean	Standard deviation	Median
1. Installation of combustion cycle power stations (10–15 MW) fuelled by olive oil industry residues	4.44	0.726	5
2. Installation of combustion cycle pw. stations (10–15 MW) fuelled by olive pruning residues	4.11	0.782	4
3. Installation of gasification–based pw. stations (10–15 MW) fuelled by olive pruning residues	4.22	0.667	4
4. Installation of gasification-based pw. stat. (10–15 MW) fuelled by wood industry residues	3.67	1.000	4
5. Installation of biogas plants fuelled by olive oil industry residues (5–10 MW)	3.56	0.882	4
6. Installation of biogas plants fuelled by cattle wastes (5–10 MW)	3.00	1.118	3
7. Installation of CHP plants for the exploitation of water treatment station biogas (0.5–2 MW)	3.33	1.225	3
8. Installation of biogas plants fuelled by urban residues (1–5 MW)	3.33	1.323	3
9. Installation of biomass domestic heating systems	3.33	1.414	4
10. Installation of biomass heating systems at educational centres	3.44	1.424	4
11. Installation of biomass heating systems at industry and services	3.89	1.054	4
12. Building of new hydro plants on existing and future dams (10–30 MW)	3.11	1.054	3
13. Building of new small hydro plants on waterfalls and watercourses (0.5–10 MW)	3.67	0.707	4
14. Refurbishing of old hydro plants (0.25–5 MW)	4.00	0.707	4
15. Domestic isolated PV systems (2–5 kW)	3.78	0.833	4
16. Isolated PV systems in farming applications (2–5 kW)	4.33	1.118	5
17. Domestic grid connected PV systems (2–5 kW)	3.33	1.225	4
18. Grid connected PV systems at companies and public administrations (30–100 kW)	3.56	1.333	3
19. Large grid connected PV systems (200–1000 kW)	2.89	1.054	3
20. Single-family domestic solar-thermal heating systems installation	4.78	0.441	5
21. Communities domestic solar-thermal heating systems installation	4.78	0.441	5
22. Solar-thermal heating systems installation at hotels and services sector	4.89	0.333	5
23. Solar-thermal heating systems installation at industry	4.44	0.527	4
24. Solar-thermal gas hybrid installations (2–20 MW)	3.44	0.726	3
25. Low-power isolated wind systems (5–250 kW)	3.11	0.782	3
26. Wind farms (5–30 MW)	4.11	0.782	4
27. Energy crops exploitation in combustion cycles	2.67	1.000	3
28. Biofuel generation through energy crops	2.89	1.453	2

- *Environmental criteria*
  5. Sustainability according to CO_2 emissions.
  6. Sustainability according to other emissions (SO_2, NO_x).
  7. Sustainability according to other impacts (noise, visual impact, landscape, ...).
- *Socioeconomic criteria*
  8. Job creation.
  9. Financial requirements.
  10. Compatibility with local, regional and national policies.
- *Delphi criterion*
  11. Expert valuation.

Each of the alternatives were quantify in every one of the criteria. Decision matrix obtained so far is shown in Table 3.

Table 3
Decision matrix of MCDA phase.

Type	Criteria										
	1	2	3	4	5	6	7	8	9	10	11
	MAX	MAX	MAX	MAX	MIN	MIN	MIN	MAX	MIN	MAX	MAX
Alternative											
1	2.107	4	2	5	50.1	0.08	4	1.75	1,442	4	4.52
2	2.107	4	2	4	50.1	0.08	4	1.75	1,442	4	4.09
3	2.007	3	1	4	50.1	0.08	3	1.75	1,442	3	4.27
4	2.007	3	1	5	50.1	0.08	3	1.75	1,442	3	3.76
5	2.007	2	2	5	73	0.61	3	1.75	1,503	3	3.45
6	2.007	3	2	4	73	0.61	3	1.75	1,503	3	3.19
7	2.007	3	2	4	73	0.61	3	1.75	1,503	3	3.42
8	2.007	3	2	4	73	0.61	3	1.75	1,503	2	3.39
9	0.076	4	3	4	25	0.04	2	1.75	240.9	3	3.67
10	0.096	4	3	4	25	0.04	2	1.75	151.4	3	3.77
11	0.076	4	3	4	25	0.04	3	1.75	62.02	3	4.1
12	0.344	5	1	3	11.6	0.025	4	0.30	601	1	3.33
13	0.502	5	2	3	9	0.1	2	0.30	1,202	3	3.69
14	0.502	5	2	3	9	0.1	2	0.30	1,202	4	4.11
15	0.416	5	5	4	75	0.4	1	1.02	13,222	3	3.91
16	0.416	5	5	4	75	0.4	1	1.02	13,222	3	4.29
17	0.416	4	5	4	60	0.4	2	1.02	6,611	4	3.38
18	0.416	4	5	4	60	0.4	2	1.02	6,611	4	3.74
19	0.416	4	4	4	60	0.4	2	1.02	6,611	3	2.97
20	0.143	5	5	4	17.98	0.147	1	1.12	729.8	3	4.63
21	0.143	4	4	4	17.98	0.147	1	1.12	472.2	3	4.81
22	0.143	4	4	4	17.98	0.147	2	1.12	472.2	3	4.91
23	0.143	3	3	4	17.98	0.147	2	1.12	472.2	3	4.31
24	0.645	2	1	4	26	0.19	3	1.12	2,524	3	3.57
25	0.631	4	3	3	18.06	0.08	2	0.30	871.5	3	3.21
26	0.631	5	2	3	18.06	0.08	5	0.30	871.5	3	4.09
27	2.007	3	2	3	27.36	0.94	4	1.75	1,442	3	2.89
28	2.007	2	1	3	27.36	0.94	3	1.75	1,442	3	2.89

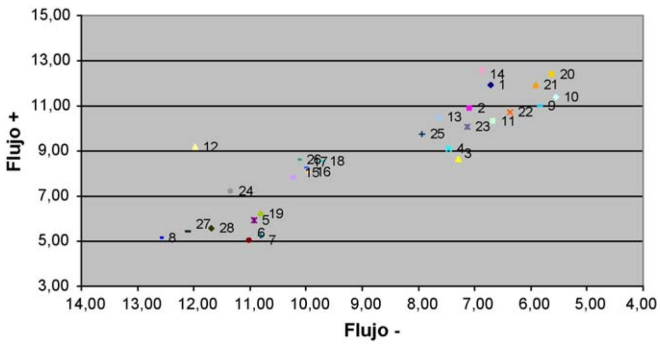

Fig. 3. MCDA process: flux diagram for environmental scenario.

PROMETHEE method was selected to perform multicriteria decision analysis. Incoming (positive) and outcoming (negative) fluxes were calculated and prioritization of alternatives was established in three different scenarios. Flux diagram concerning environmental scenario is presented in Fig. 3.

Multicriteria analysis allowed us to establish three different priority levels. Fourteen alternatives were set as A priority, six were set as B, an eight were set as C.

6.4. Strategies selection and targets establishment

Final actions selected and energy targets to be met are shown in Table 4. For the purpose of the energy plan, the whole set of 28 strategies was selected including the group of alternatives that were worse appreciated and that should become lower level priority actions.

6.5. Results

Final result of such process presents 472 MW of power installed in year 2010, by means of twenty strategies concerning electricity generation with renewable resources, leading to an annual production of 1630 GWh out of the region. Concerning thermal production, target is fixed in 253.46 ktep through eight strategies mainly focused on biomass and solar thermal (Tables 5 and 6).

Future evolution of provincial energy structure was also estimated, establishing a growth hypothesis up to year 2010. In this way, contribution of renewables to electricity consumption is fixed in 43.3%, while renewables thermal production will contribute in 17.6% to final energy total demand. Overall contribution of renewable sources in provincial energy system is finally set to 28.3%, in terms of final energy (Fig. 4).

Table 5
Energy targets for electrical generation. Year 2010.

	Power (MW)	Yield (MWh)
Electrical generation from biomass	153.3	1,111,250
Hydraulics	225.5	306,625
Solar PV (isolated)	1.1	1,595
Solar PV (grid connected)	5.5	7,975
Solar thermoelectric	12.0	27,000
Wind energy	72.0	158,400
Electricity from energy crops	2.5	17,000
Total	472.1	1,630,345

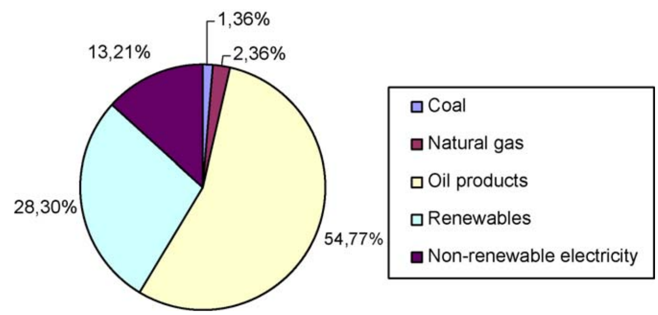

Fig. 4. Provincial energy structure (final energy). Year 2010.

Table 4
Resulting actions and energy targets.

Action	2010 target
1. Installation of combustion cycle power stations (10–15 MW) fuelled by olive oil industry residues	75 MW
2. Installation of combustion cycle pw. stations (10–15 MW) fuelled by olive pruning residues	30 MW
3. Installation of gasification-based pw. stations (10–15 MW) fuelled by olive pruning residues	20 MW
4. Installation of gasification-based pw. stat. (10–15 MW) fuelled by wood industry residues	8 MW
5. Installation of biogas plants fuelled by olive oil industry residues (5–10 MW)	10 MW
6. Installation of biogas plants fuelled by cattle wastes (5–10 MW)	6.5 MW
7. Installation of CHP plants for the exploitation of water treatment station biogas (0.5–2 MW)	1.5 MW
8. Installation of biogas plants fuelled by urban residues (1–5 MW)	2.5 MW
9. Installation of biomass domestic heating systems	980 Unit
10. Installation of biomass heating systems at educational centres	60 Unit
11. Installation of biomass heating systems at industry and services	510 Unit
12. Hydro plants on existing and future dams (10–30 MW)	160.0 MW
13. Small hydro plants on waterfalls and watercourses (0.5–10 MW)	58.5 MW
14. Refurbishing of old hydro plants (0.25–5 MW)	7.0 MW
15. Domestic isolated PV systems (2–5 kW)	0.5 MW
16. Isolated PV systems in farming applications (2–5 kW)	0.6 MW
17. Domestic grid connected PV systems (2–5 kW)	0.50 MW
18. Grid connected PV systems at companies and public administrations (30–100 kW)	3.00 MW
19. Large grid connected PV systems (200–1000 kW)	2.00 MW
20. Single-family domestic solar-thermal heating systems installation	10,500 Unit
21. Communities domestic solar-thermal heating systems installation	10,200 Unit
22. Solar-thermal heating systems installation at hotels and services sector	11,300 Unit
23. Solar-thermal heating systems installation at industry	5,500 Unit
24. Solar-thermal gas hybrid installations (2–20 MW)	12.0 MW
25. Low-power isolated wind systems (5–250 kW)	2.0 MW
26. Wind farms (5–30 MW)	70.0 MW
27. Energy crops exploitation in combustion cycles	2.5 MW
28. Biofuel generation through energy crops	2.89

Table 6
Energy targets for thermal generation. Year 2010.

	Increase (tep)	Production (ktep)
Thermal generation from biomass	14,118	249.92
Solar thermal	2,580	2.86
Biofuel from energy crops	700	0.7
Total		253.46

7. Conclusions

Energy planning processes under sustainable development criteria have made extensive use of multicriteria decision techniques, where environmental criteria have been incorporated in the assessment, and also experts' opinion methods and techniques derived from territorial strategic planning.

The analysis of these methodologies and tools is useful to highlight their main advantages and to harness them in the proposal of a combined planning method involving the three approaches. This method allows to establish, al regional level, development strategies concerning mainly renewable resources, quantifying and ranking them. On the other hand, the method is easily interrelated with collective participation techniques that may assure, as a key factor to success, the involvement of the community in the regional planning process.

The application of the proposed methodology to Jaén Province has generated a series of strategies for renewable energy development in concerned region, and a set of quantified targets to be achieved. The objective regarding electricity production from renewable resources, on year 2010, is fixed above 1630 GWh, which represents a 43% of the total foreseeable electricity consumption. Overall contribution of renewable sources in provincial energy system is finally set to 28.3%, in terms of final energy.

Planned development of renewables from current situation shows an increase of 42.2%, standing out mainly development of solar energy, both thermal an photovoltaic, which are showing an increase above 2000%.

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